

13. A photodiode according to claim 8; wherein the first conductivity type comprises p-type conductivity.

14. A photodiode according to claim 13; wherein the second conductivity type comprises n-type conductivity.

IN THE ABSTRACT:

Delete the abstract now of record and insert therefor the new abstract submitted herewith of on a separate sheet.

ADDITIONAL FEES:

No additional fees are believed required; however, should it be determined that a fee is due, authorization is hereby given to charge any such fee to our Deposit Account No. 01-0268.

REMARKS

In the last Office Action, the Examiner objected to the title of the invention as not being descriptive. Claims 1 and 3 were rejected under 35 U.S.C. §102(b) as being anticipated by the international journal publication by Wen-Shiung Lour and Chung-Cheng Chang in Solid States Electronics, vol. 39, issue 9, pp. 1295-1298 (1986) ("Chang et al."). Claim 1 was further rejected under 35 U.S.C. §102(b) as being anticipated by Japanese Patent No. 7-106415 ("Japan '415").

Claim 2 was rejected under 35 U.S.C. §103(a) as being unpatentable over Chang et al.

In accordance with the present response, the specification has been suitably revised to correct informalities, to provide antecedent basis for the claim language, and to place it in better conformance with U.S. practice. The title of the invention has been changed to "SHORT-WAVELENGTH PHOTODIODE OF ENHANCED SENSITIVITY WITH LOW LEAK CURRENT AND METHOD OF MANUFACTURING PHOTODIODE" to more clearly reflect the invention to which the claims are directed. Original independent claim 1 has been amended to further patentably distinguish from the prior art of record. Original claims 1-3 have also been amended in formal respects to improve the wording thereof. New claims 4-14 have been added to provide a fuller scope of coverage. A new, more descriptive abstract has been substituted for the original abstract.

Attached hereto is a marked-up version of the changes made to the specification and claims by the current amendment. The attached pages i-vii are captioned "VERSION WITH MARKINGS TO SHOW CHANGES MADE".

Applicant respectfully requests reconsideration of his application in light of the following discussion.

The present invention is directed to a short-wavelength photodiode of enhanced sensitivity with low leak current, and to a method of manufacturing the photodiode.

As described in the specification (pgs. 1-3), the detection of light sensitivity in a short wavelength region by conventional photodiodes is inferior. Furthermore, the conventional photodiodes are associated with high leak current.

The present invention overcomes the drawbacks of the conventional art. Fig. 1 shows a photodiode according to the present invention embodied in amended independent claim 1. The photodiode comprises an optical detection portion for detecting an optical signal and outputting a photoelectric conversion signal. The optical detection portion has a semiconductor substrate 1 of a first conductive type and semiconductor layers 2a, 2b of a second conductive type formed in spaced-apart relation in a surface of the semiconductor substrate so that an etched surface portion of the semiconductor substrate 1 is disposed between the semiconductor layers 2a, 2b.

In another aspect, the present invention is directed to a method of manufacturing a photodiode. As embodied in new independent claim 8, the method comprises the steps of providing a semiconductor substrate of a first conductivity type, forming a plurality of semiconductor layers of a second

conductivity type in spaced-apart relation in a surface of the semiconductor substrate so that a surface portion of the semiconductor substrate is disposed between the semiconductor layers, and etching the surface portion of the semiconductor substrate.

By the foregoing photodiode construction and manufacturing method, the present invention provides a short-wavelength photodiode of enhanced sensitivity and with low leak current. By etching the surface portion of the semiconductor substrate which is disposed between the semiconductor layers, leak current is controlled without greatly influencing the photo sensitivity of the photodiode.

The prior art of record does not disclose or suggest the subject matter recited in amended claims 1-3 and newly added claims 4-14.

Claims 1 and 3 were rejected under 35 U.S.C. §102(b) as being anticipated by Chang et al. Applicant respectfully traverses this rejection and submits that amended claims 1 and 3 recite subject matter which is not identically disclosed or described in Chang et al.

Amended independent claim 1 is directed to a photodiode and requires an optical detection portion having a semiconductor substrate of a first conductive type and a plurality of semiconductor layers of a second conductive type formed in spaced-apart relation in a surface of the

semiconductor substrate so that an etched surface portion of the semiconductor substrate is disposed between the semiconductor layers.

Chang et al. disclose a photodiode having a semiconductor substrate (absorption layer) and a pair of semiconductor layers of n-type conductivity formed in spaced-apart relation on the surface of the semiconductor substrate. However, Chang et al. do not disclose or describe a plurality of semiconductor layers formed in spaced-apart relation in a surface of the semiconductor substrate so that an etched surface portion of the semiconductor substrate is disposed between the semiconductor layers. In the absence of the foregoing disclosure recited in amended independent claim 1, anticipation cannot be found. See, e.g., W.L. Gore & Associates v. Garlock, Inc., 220 USPQ 303, 313 (Fed. Cir. 1983), cert. denied, 469 U.S. 851 (1984) ("Anticipation requires the disclosure in a single prior art reference of each element of the claim under consideration"); Continental Can Co. USA v. Monsanto Co., 20 USPQ2d 1746, 1748 (Fed. Cir. 1991) ("When more than one reference is required to establish unpatentability of the claimed invention anticipation under § 102 can not be found."); Lindemann Maschinenfabrik GmbH v. American Hoist & Derrick Co., 221 USPQ 481, 485 (Fed. Cir. 1984) (emphasis added) ("Anticipation requires the presence in

a single prior art reference disclosure of each and every element of the claimed invention, arranged as in the claim").

Stated otherwise, there must be no difference between the claimed invention and the reference disclosure, as viewed by a person of ordinary skill in the field of the invention. This standard is clearly not satisfied by the Chang et al. disclosure for the reasons stated above. Furthermore, Chang et al. do not suggest the claimed subject matter and, therefore, would not have motivated one skilled in the art to modify Chang et al.'s photodiode to arrive at the claimed invention.

Claim 3 depends on and contains all of the limitations of amended independent claim 1 and, therefore, distinguishes from the reference at least in the same manner as claim 1.

In view of the foregoing, applicant respectfully requests that the rejection of claims 1 and 3 under 35 U.S.C. §102(b) as being anticipated by Chang et al. be withdrawn.

Claim 1 was rejected under 35 U.S.C. §102(b) as being anticipated by Japan '415. Applicant respectfully traverses this rejection and submits that amended independent claim 1 recites subject matter which is not identically disclosed or described in Japan '415.

Amended independent claim 1 is directed to a photodiode as set forth above for the rejection of claims 1 and 3 under 35 U.S. §102(b) as being anticipated by Chang et al.

Japan '415 discloses a photodiode having a p-type semiconductor substrate and n-type semiconductor layers disposed on a surface of the semiconductor substrate. However, Japan '415 does not disclose or describe a plurality of semiconductor layers formed in spaced-apart relation in a surface of the semiconductor substrate so that an etched surface portion of the semiconductor substrate is disposed between the semiconductor layers. Since Japan '415 does not disclose or describe the foregoing feature recited in amended independent claim 1, there can be no anticipation by Japan '415 under 35 U.S.C. §102(b). That is, since each and every limitation of amended claim 1 is not found in Japan '415, the reference does not anticipate the claimed invention. See In re Lange, 209 USPQ 288, 293 (CCPA 1981). Furthermore, Japan '415 does not suggest the claimed subject matter and, therefore, would not have motivated one skilled in the art to modify the photodiode disclosed in this reference to arrive at the claimed invention.

In view of the foregoing, applicant respectfully requests that the rejection of claim 1 under 35 U.S.C. §102(b) as being anticipated by Japan '415 be withdrawn.

Claim 2 was rejected under 35 U.S.C. §103(a) as being unpatentable over Chang et al. Applicant respectfully traverses this rejection and submits that the teachings of Chang et al. do not disclose or suggest the subject matter recited in claim 2.

Chang et al. do not disclose or suggest the subject matter recited in amended independent claim 1 as set forth above for the rejection of claims 1 and 3 under 35 U.S.C. §102(b). Claim 2 depends on and contains all of the limitations of amended independent claim 1 and, therefore, distinguishes from the reference at least in the same manner as claim 1.

In view of the foregoing, applicant respectfully requests that the rejection of claim 2 under 35 U.S.C. §103(a) as being unpatentable over Chang et al. be withdrawn.

Applicant respectfully submits that the prior art of record also does not disclose or suggest the subject matter recited in newly added claims 4-14.

New claims 4-7 depend on and contain all of the limitations of amended independent claim 1 and, therefore, distinguish from the prior art of record at least in the same manner as claim 1.

New independent claim 8 is directed to a method of manufacturing a photodiode and recites the steps of providing a semiconductor substrate of a first conductivity type,

forming a plurality of semiconductor layers of a second conductivity type in spaced-apart relation in a surface of the semiconductor substrate so that a surface portion of the semiconductor substrate is disposed between the semiconductor layers, and etching the surface portion of the semiconductor substrate. No corresponding combination of steps is disclosed or suggested by the prior art of record.

New claims 9-14 depend on and contain all of the limitations of independent claim 8 and, therefore, distinguish from the prior art of record at least in the same manner as claim 8.

In view of the foregoing amendments and discussion, the application is believed to be in allowable form. Accordingly, favorable reconsideration and allowance of the claims are most respectfully requested.

Respectfully submitted,

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VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE SPECIFICATION:

Paragraph beginning at line 3 of page 1 has been amended as follows:

The present invention relates to a photodiode, and particularly to a structure for improving the short wavelength region photo sensitivity of a photodiode, and to a method of manufacturing the photodiode.

Paragraph beginning at line 9 of page 3 has been amended as follows:

The present invention has been made in view of the [above] foregoing [circumstances] drawbacks in the conventional art, and has an object to provide a photodiode which can improve the photo sensitivity in a shorter wavelength region, as compared with a conventional photodiode, without increasing leak current.

Paragraph beginning at line 14 of page 3 has been amended as follows:

In order to solve the above-mentioned problem, according to the present invention, a photodiode includes a first conductive type semiconductor region, and a plurality of second conductive type semiconductor layers formed on the

surface of the first conductive type semiconductor region, the first conductive type semiconductor region and the plurality of second conductive type semiconductor layers constituting an optical detection portion for detecting an optical signal and outputting its photoelectric conversion signal, wherein the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed. [Like this,] By this construction, since the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed, the interface level of the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed.

Paragraph beginning at line 7 of page 4 has been amended as follows:

[Besides] Furthermore, the surface of the first conductive type semiconductor region is removed by a wet etching method, so that the region can be removed without generating an interface level due to etching damage.

Paragraph beginning at line 14 of page 4 has been amended as follows:

When a reverse bias is applied to the photodiode constituted by the first conductive type semiconductor region

and the second conductive type semiconductor layers, a depletion layer is extended in accordance with the bias voltage. Since the depletion layer is extended not only in the vertical direction but also in the horizontal direction, the depletion layer is extended not only in the vertical direction but also in the horizontal direction, the depletion layer is also formed on the surface of the first conductive type semiconductor region, and the photo sensitivity in a short wavelength region is improved. At this time, [since] the respective second conductive type semiconductor layers are made to have the same potential. Thus, when the distance between the second conductive type semiconductor layers is made about twice the width of the depletion layer, since the depletion layers of adjacent photodiodes formed of the first conductive type semiconductor region and the second conductive type semiconductor layers just come in contact with each other, the efficiency is excellent.

Paragraph beginning at line 12 of page 5 has been amended as follows:

[Besides] Furthermore, when the interface level of the surface of the first conductive type semiconductor region is removed by using the wet etching method, the interface level can be removed without generating an interface level due to etching damage.

Paragraph beginning at line 2 of page 6 has been amended as follows:

An embodiment of the present invention will be described below with reference to the drawings. Fig. 1 is a schematic sectional view showing an embodiment of a photodiode of the present invention.

Paragraph beginning at line 2 of page 7 has been amended as follows:

It is [needless to say] understood that the respective conductive types may be reversed. For example, a plurality of first conductive type semiconductor layers are formed on a second conductive type semiconductor region, and the interface level of the surface of the second conductive type semiconductor region between the first conductive type semiconductor layers is removed by a wet etching method.

Paragraph beginning at line 9 of page 7 has been amended as follows:

Further, it is [needless to say] understood that a portion between the second conductive type semiconductor layers is not limited to a only one portion, but plural portions may be formed.

Paragraph beginning at lin 6 of page 8 has been amended as follows:

[Besides,] Furthermore, since the interface level of the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed, the leak current can be suppressed without greatly influencing the photo sensitivity.

Paragraph beginning at line 10 of page 8 has been amended as follows:

[Besides,] Furthermore, since the interface level of the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed by using the wet etching method, the interface level can be removed without generating an interface level due to etching damage.

IN THE CLAIMS:

Claims 1-3 have been amended as follows:

1. (Amended) A photodiode comprising: an optical detection portion for detecting an optical signal and outputting a photoelectric conversion signal, the optical detection portion having a semiconductor substrate of a first conductive type [semiconductor region,] and a plurality of

semiconductor layers of a second conductive type
[semiconductor layers] formed [on] in spaced-apart relation in
a surface of the semiconductor substrate so that an etched
surface portion of the semiconductor substrate is disposed
between the semiconductor layers. [first conductive type
semiconductor region, the first conductive type semiconductor
region and the plurality of second conductive type
semiconductor layers constituting an optical detection portion
for detecting an optical signal and outputting its
photoelectric conversion signal, wherein the surface of the
first conductive type semiconductor region between the second
conductive type semiconductor layers is removed.]

2. (Amended) A photodiode according to claim 1[,];
further comprising a depletion layer formed in the
semiconductor substrate by application of a reverse bias to
the photodiode; wherein a distance between the [second
conductive type] semiconductor layers [formed on the surface
of the first conductive type semiconductor region] is 0.5 to 2
times a width of the [a] depletion layer [in a horizontal
direction formed by reverse bias application].

3. (Amended) A photodiode according to claim 1[,];
wherein the etched surface portion of the [first conductive
type] semiconductor substrate comprises a wet-etched surface

portion [region between the second conductive type semiconductor layers is removed by a wet etching method].